SOLAR ENERGY
TECHNOLOGIES OFFICE
U.S. Department Of Energy

Optimal Reconfiguration and Resilient Control Framework for Real-Time Photovoltaic Dispatch to Manage Critical Infrastructure (ReDis-PV)

Lead Organization: The University of North Carolina at Charlotte (UNCC)

Other Partners

Argonne National Laboratory, Idaho National Laboratory, Florida International University, Clemson University, New Mexico State University, OPAL RT Technologies, Duke Energy Corporation

Sukumar Kamalasadan
Duke Energy Distinguished Professor
UNC Charlotte
skamalas@uncc.edu

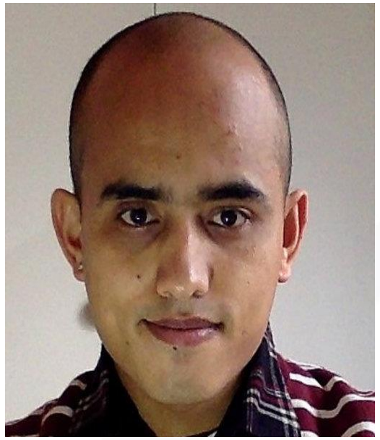
Team Leads

Sukumar Kamalasadan
UNC Charlotte
Expertise: Power System Modeling and Control

Sukumar Brahma
Clemson University
Expertise: Power System Protection

Sumit Paudyal
Florida International University
Expertise: Power System Optimization

Jay Misra
New Mexico State University
Expertise: Communication and Cyber Systems



Rojan Bhattarai
Argonne National Laboratory
Expertise: Grid Modeling and Control

Humberto Garcia
Idaho National Laboratory
Expertise: Threat Modeling and Control

Sudipta Chakraborty
Opal RT Technologies
Expertise: Real-time Modeling

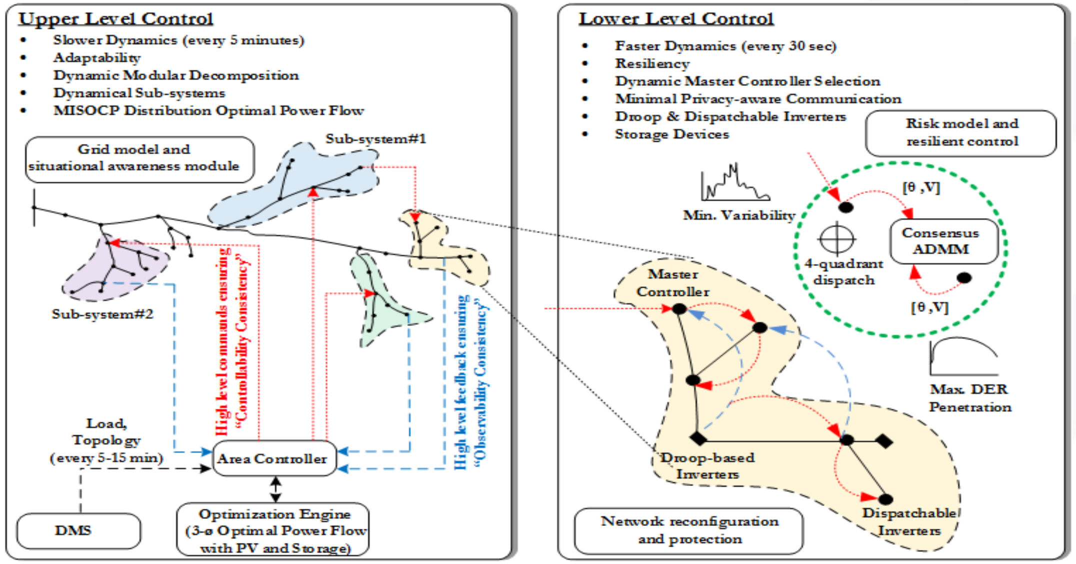
Sherif Abdelrazek
Duke Energy Corporation
Expertise: Distributed Energy Technologies

Project Summary

summary slide describing Project Objectives, Technical Approach, Team, Budget, and Outcomes.

Project Summary and Technical Approach: The objective of this proposed project is to design a grid management tool (ReDis-PV) that is threat aware, resilient, grid reconfigurable, and can form dynamic clusters to optimally manage PV and energy storage for improving grid resiliency and supporting critical infrastructure. ReDis-PV consists of: a) a situational awareness module b) proactive resiliency diagnosis and predictive adaptation module c) a hierarchical control with dynamic clustering and organizational module, d) optimal power flow module, and e) a network reconfiguration and cyber security threat detection module. The proposed approach is to develop a vendor agnostic tool comprising of the above-mentioned modules requiring minimal communication between active PV stations, storage nodes, and distribution control center (DCC).

Team: Florida International University, Clemson University, New Mexico State University, Argonne National Laboratory, Idaho National Laboratory, OPAL RT Technologies and Duke Energy.



Milestone: Year-1: Tool design for performance evaluation with 100+ active nodes
Year-2: Tool design for performance evaluation with 1000+ active nodes
Year-3: HIL Validation and Demonstration

Key Milestones & Outcomes

Year 1:	Tool that can perform grid resiliency improvement and critical infrastructure support for 100+ nodes. Design testing and validation.
Year 2:	Tool that can perform grid resiliency improvement and critical infrastructure support for 1000+ nodes. Interdependency testing and scalability evaluation.
Year 3:	Tool that can be deployed in the field in a small scale and fully deployable in HIL simulation.

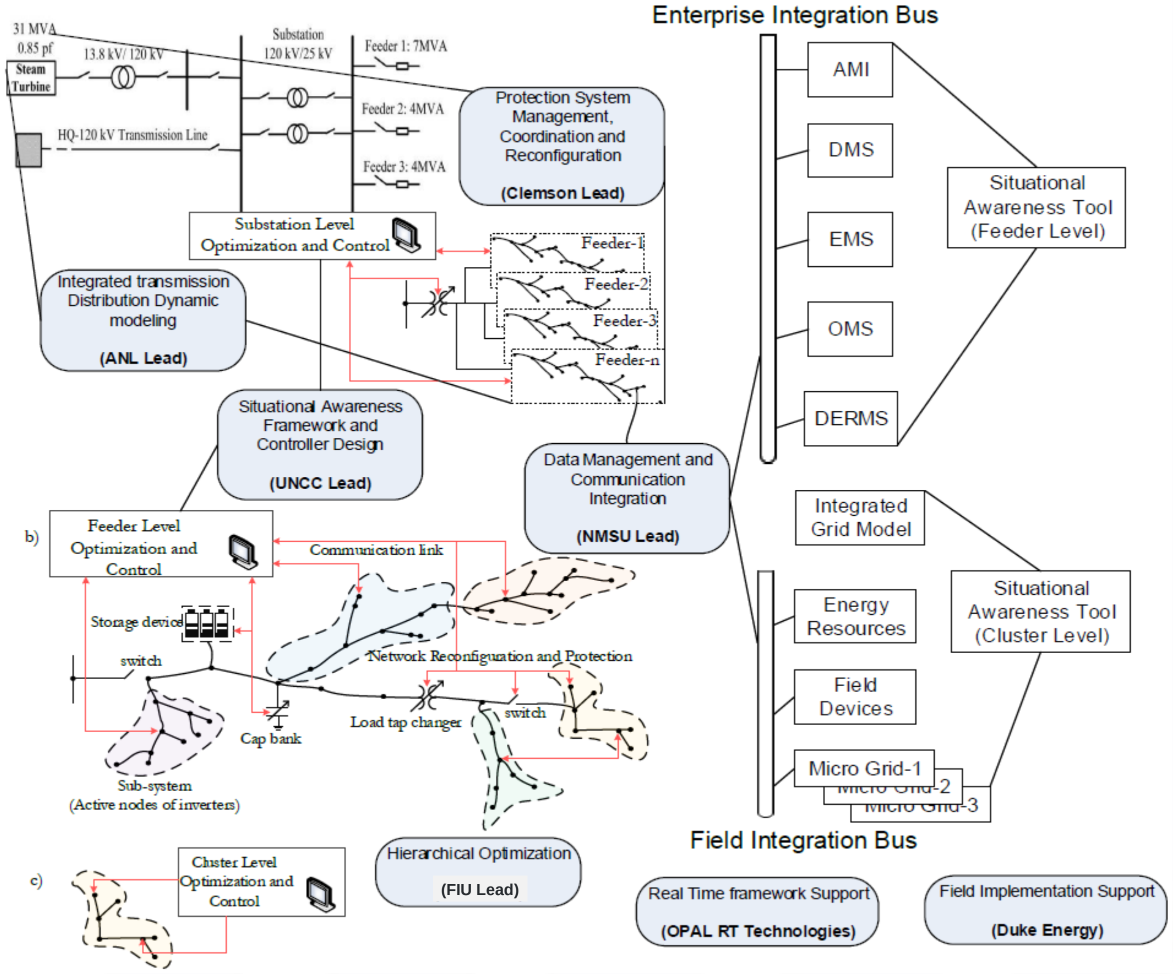
Project Impact: We will focus on the following specific performance metrics compare to baseline with the integration of ReDis-PV - net capacity factor improvement (by 15 %), increase in PV penetration (by 10 %), both reliability and resilience improvement by 15% and PV dispatchability by 10% with optimal energy storage size which is has significant impact on improving large grid scale reliability and resiliency.

Technical Objectives

Overall Goal: Develop an operational tool that manage DER clusters in the power distribution system to facilitate improving grid reliability and resiliency and at the same time supporting critical infrastructure.

Technical Objectives:

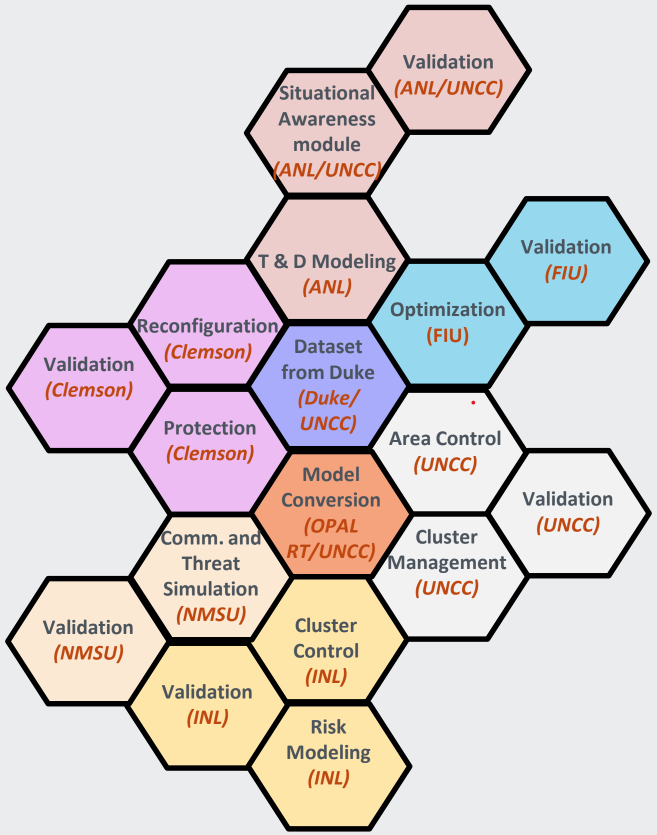
1. Develop dynamic integrated transmission and distribution model with situational awareness module.
2. Design and develop a cluster organization and hierarchical area control module.
3. Design and develop a grid level optimization module.
4. Design a dynamic cluster control architecture and risk/threat resiliency module.
5. Design a network reconfiguration module.
6. Design a grid-aware communication and cyber security threat detection module.
7. Develop a framework for lab scale and field implementation and demonstrate in the lab and field.



Overall functional diagram of the proposed tool

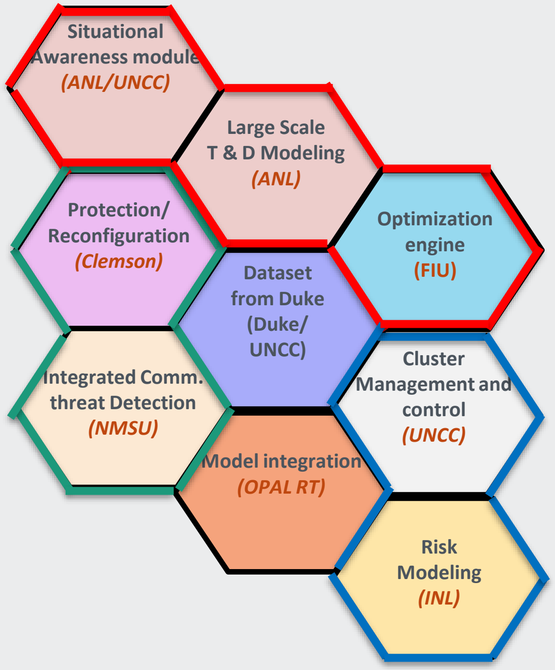
Overall Approach, Main Modules and Integration Process

(Module Independent development and validation)



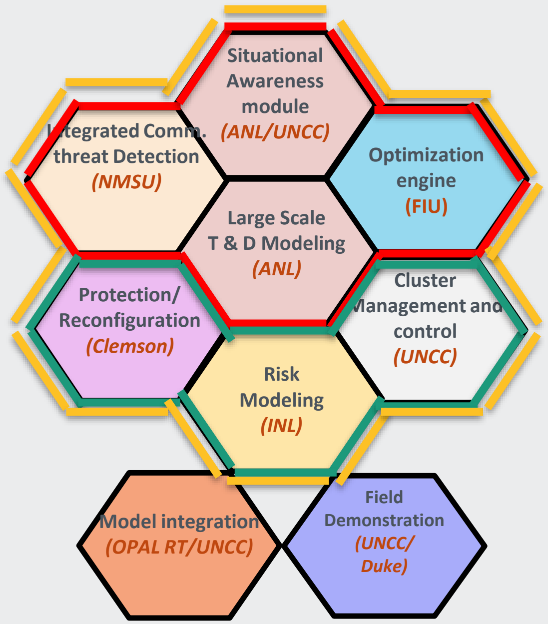
Features: Modular testing and evaluation with real model and data set

(Module Integration, scalability and validation)



Features: Interdepend evaluation with clear test plan and verification of integrated models

(Tool Delivery and Demonstration of DER Management Framework)



Features: Real-time, HIL and field testing that shows the pathway for large scale deployment

Overall Anticipated Outcome and Relevance

- **Overall Outcome:**
  - Integrated tool that works in conjunction with the legacy and inverter-based controllers, existing communication system, meters, and DMS to monitor the 'health' of distribution grid with high penetration of PVs and other DERs.
  - A management mechanism to utilize PVs, Energy Storage and flexible loads, to support critical infrastructure during emergency and improve reliability during normal operation.
- **Main Features:**
  - Capable of dynamically updating the grid model during normal operation and during cyber or physical threats.
  - Capable of assessing cyber and physical security and developing a risk level which is then used for managing the DERs.
  - Capable of evaluating and developing metrics for reliability, resiliency, dispatchability and penetration level.
  - Modular and can be seamlessly integrated with the existing infrastructure thus providing a non-proprietary vendor agnostic solution.
  - Capable of dynamically reconfiguring and managing DERs based on grid situation with operator override features.
- **Project Relevance:**
  - The project develops a unique tool that allows higher penetration of DERs with increased reliability and resiliency.
  - The project develop a unique situational awareness tool that can be used by the operator for organizing the DERs in terms of availability, usability and improved dispatchability.
  - A holistic approach and a unique platform that can provide threats and resiliency metrics with respect to cyber and physical intrusion considering DER integrated distribution grid.
  - **Fully in line with DOE program goals**

Technical Details of each Module

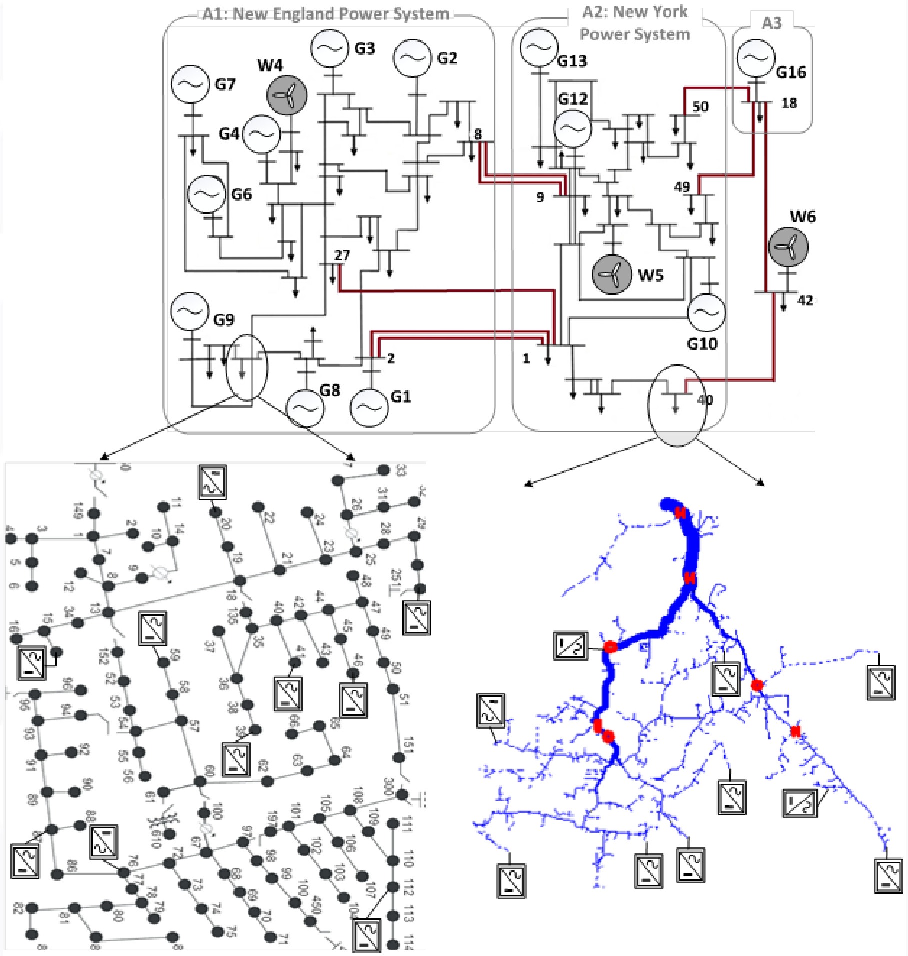
Module 1: Grid Model and situational Awareness Module

Objective: Develop an equivalent representation of transmission system followed by a detailed modeling of distribution system along with static and dynamic loads as well as various DER technologies and system protection devices. Data obtained from Duke Energy will be utilized to develop a detailed distribution system model so as to capture important features of a typical distribution feeder. Situational awareness module integrate resiliency and reliability criteria and status.

Key Innovative Aspects:

Demonstration of how the grid operators can be made more situational aware through the use of bottom up communication approach and risk informed resiliency evaluation which can lead to increased system reliability and resiliency along with higher PV penetration.

- Development of an integrated T&D system which provides a more realistic study outcomes compared to separate T and D system-based studies with certain assumptions.



Representative **integrated** T and D system

Technical Details of each Module

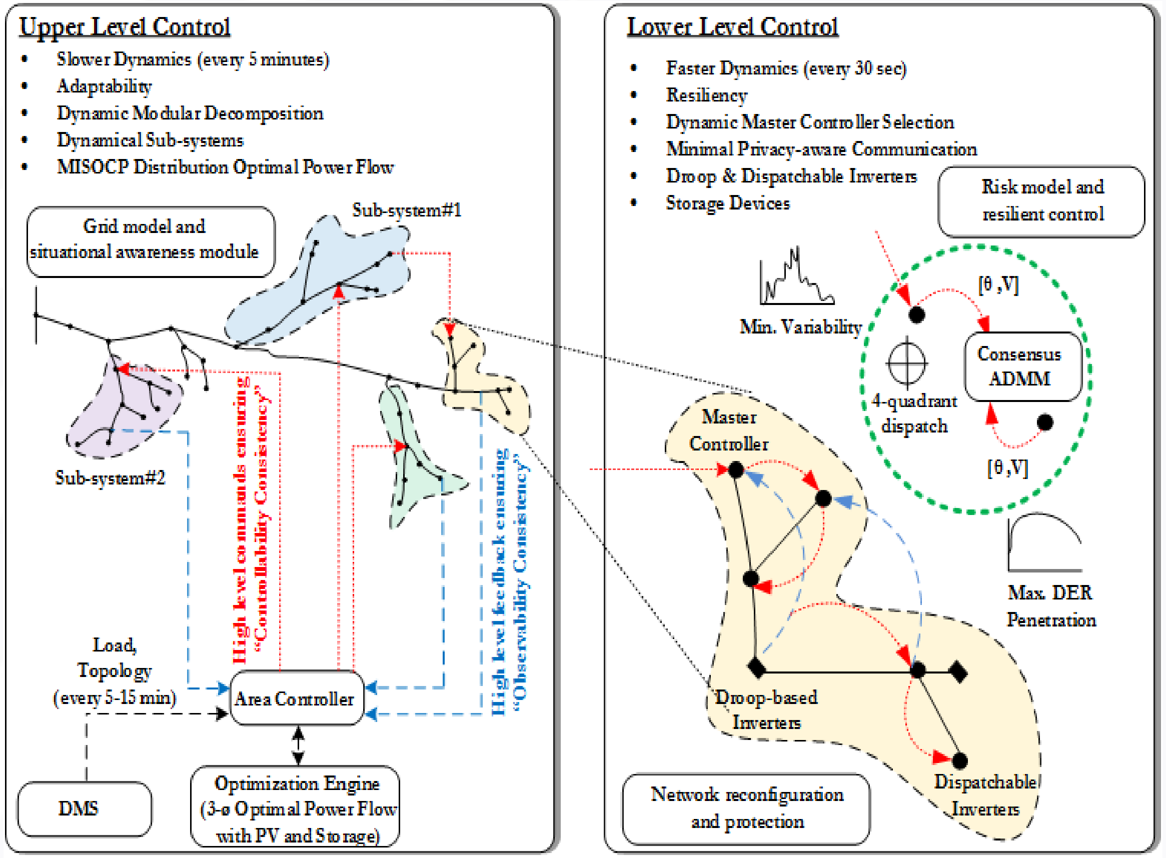
Module 2: DER Cluster Organization and Area controller Design

Objective:

- Develop coupled active and reactive power sensitivities based on measurements.
- Develop clusters based on the output from optimization and DMS signal along with measurements from legacy and other DER controllers.
- Manage DER output controlling the inverters for both active and reactive power with fully coupled active and reactive droop based and dispatchable inverter control utilizing a novel distributed management approach.

Key Innovative Aspects:

- Novel clustering algorithm based on spectral clustering and singular decomposition utilizing sensitivities.
- Novel DER management algorithm based on integrated droop based and dispatchable inverter control.



Representation of DER clusters and Area Controller

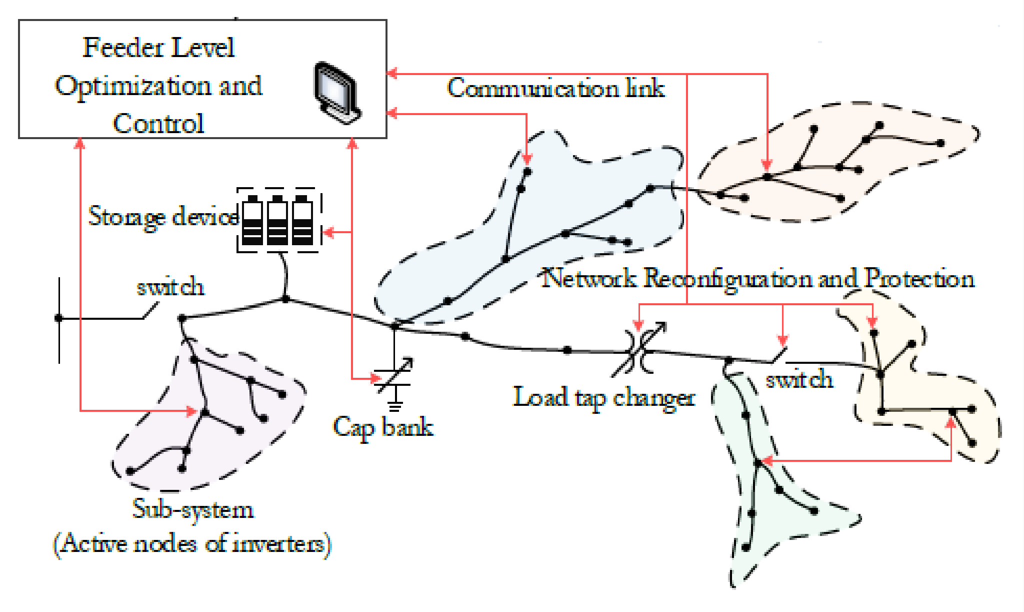
Technical Details of each Module

Module 3: Distribution Optimization Module

Objective: To develop time-scale separation, and hierarchical/distributed optimization to efficiently manage spatially separated DERs in coordination with legacy grid control equipment.

- Time-scale Separation: *Slower control* for voltage regulation type of application. Will deploy network switches, cap banks, load tap changers, inverters, and battery storage. *Faster Control* aggregation of resources to frequency control actions on bulk transmission grids. Will deploy continuously controllable resources.. e.g. inverters, battery storage.
- Hierarchical Separation: Feder Level control, Cluster level control
- Distributed Control: Coordination of multiple clusters.

Implementation Methodology: GAMS/AMPL modeling platform. State of the art solvers: MOSEK, KNITRO, CPLEX. Will be interfaced to OPAL RT for sending the set points for real time control. Will be tested in 500+ three-phase distribution system.



Key Innovation Aspects: Integer control model in SOCP model (a MISOCP formulation). This will be used for coordinating integer controllable resources.

A novel accurate three-phase Linear power flow model for real time control (not LinDistFlow as it ignores losses) with loss included. Highly scalable model for large scale T&D studies.

Technical Details of each Module

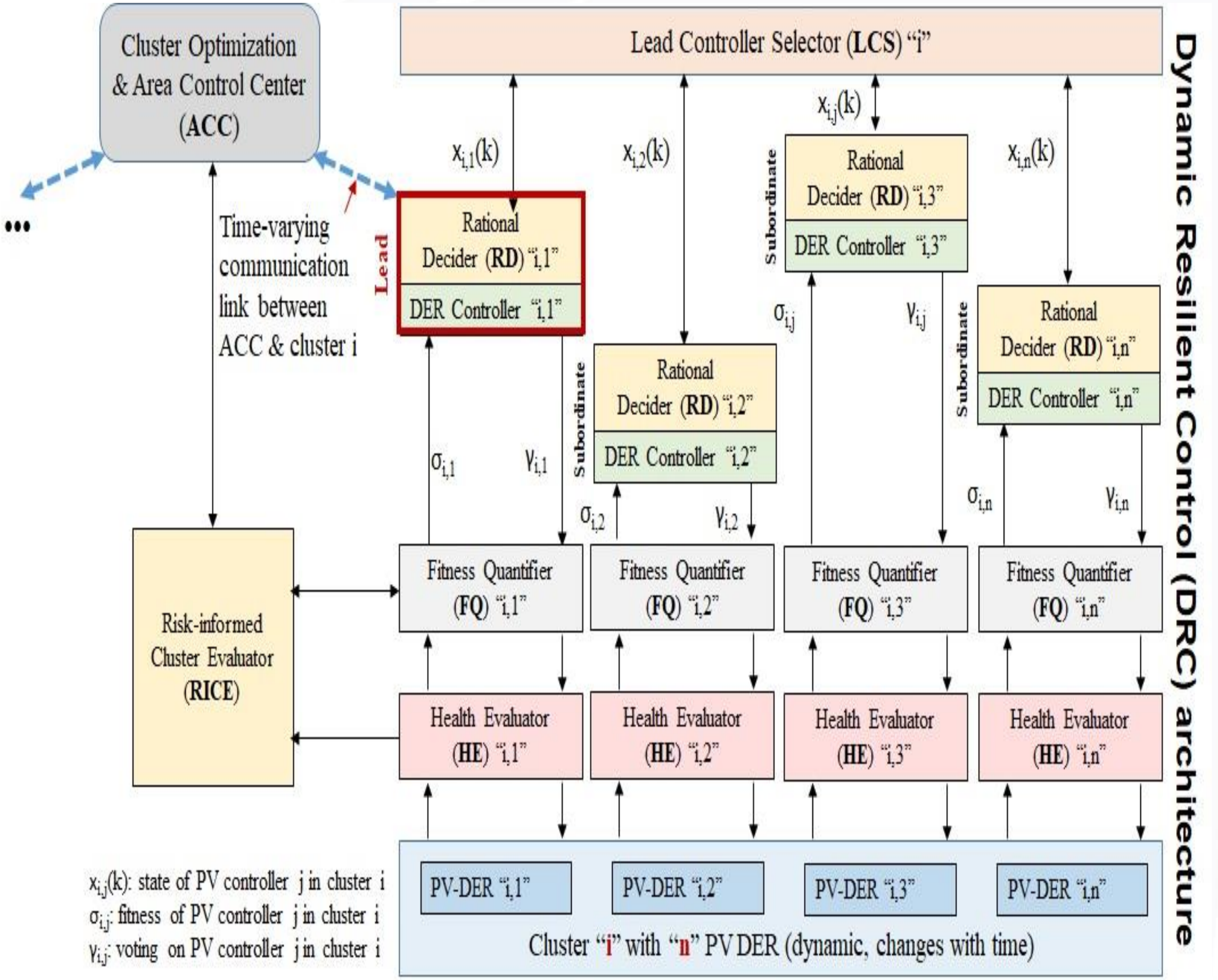
Module 4: Adaptive Cluster Control and Risk/Threat Modeling: (INL)

Objectives: Design and demonstrate an adaptive framework to dynamically select lead cluster controllers to vary vulnerability surface. Develop threat detection and mitigation algorithms to proactively respond to cyber- and physics-driven threats. Design a real-time risk and health monitoring framework for hyper-layered situational awareness.

Key Innovative Aspects:

- Randomization and moving target defense (MTD) to diminish threat success
- Real-time risk and health assessment based on observed conditions, performance objectives, and topological arrangements of dynamically-selected clusters
- Robust detection and diagnostics of hybrid (cyber plus physical) insults

Team Lead and Qualification: Dr. H.E. Garcia, lead on cyber/physical system integration, optimization & resilient controls. Multiple successful developments & demonstrations of advanced resilient monitoring and control solutions.



Adaptive control cluster and threat modeling design flow.

Technical Details of each Module

Module 5: Network Reconfiguration and Protection

Objectives: Design an adaptive, scalable, secure, and dependable protection scheme that removes the drawbacks of legacy schemes; conceive its implementation with the proposed control and communication; and extensively test using EMPT and HIL platforms.

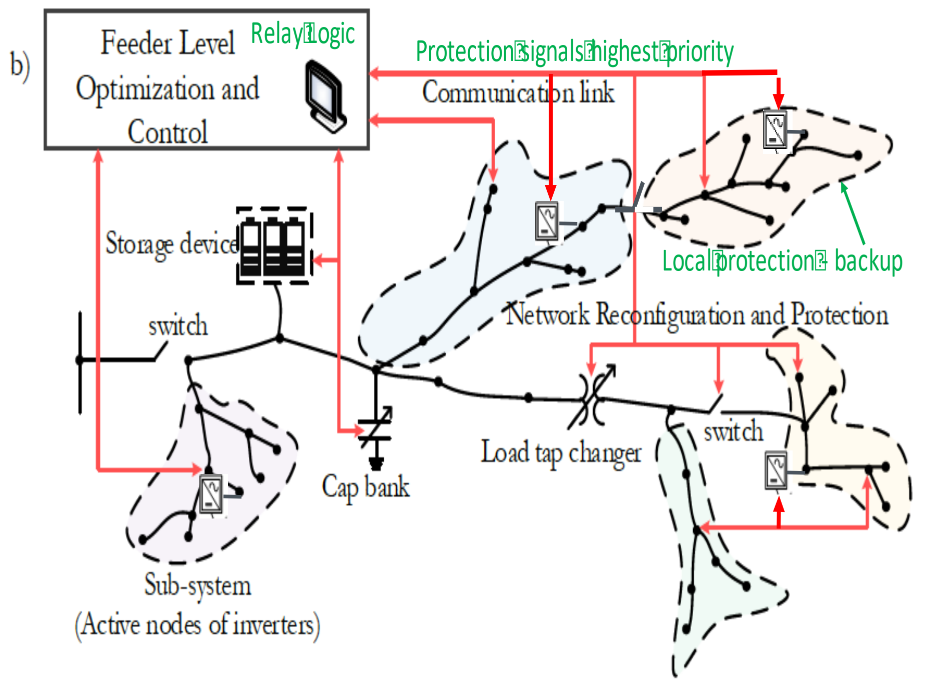
Implementation Methodology:

1) We will evaluate the legacy protection schemes in presence of new sources and operational requirements, including partial and complete islanding.

2) Based on the evaluation we will conceptualize an adaptive, dependable and secure protection scheme that is able to detect and isolate faults in presence of inverter-based generation and adapt to reconfigured network resulting from fault-driven outages, and resilience-driven scenarios, including partial and complete islanding.

3) Design the implementation using the proposed communication backbone and controller.

4) Holistically test the protection scheme on EMTP and RTDS.



Key Innovative Aspects:

1) Substantial deviation from the state of the art of distribution system protection – requires out-of-box thinking.
2) Holistic system-level approach to protection of grid of the near-future.

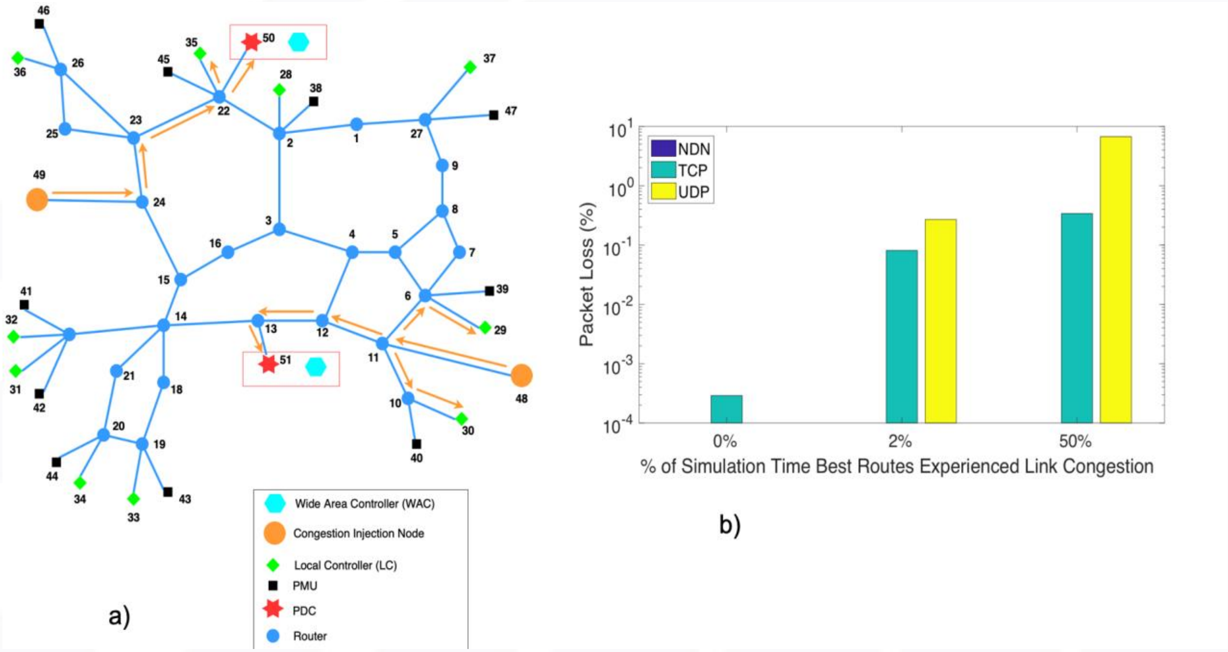
Technical Details of each Module

Module 6: Grid-aware Communication Infrastructure and Cyber Security Threat Detection

<u>**Objectives**</u>**:** Investigating the use of the information-centric networking (ICN) paradigm design to support diverse communication priorities to enable grid-aware communications.

<u>**Key Innovative Aspects**</u>**:**

- Incorporating the ICN paradigm (using Named Data Networking (NDN) architecture);
- Monte Carlo simulations resulting in a rule book for grid-network co-interaction;
- Identification of network architecture to sustain dynamic and real-time PV systems and dispatch.



This result shows that NDN in the IEEE-39 bus system provides almost negligible packet loss compared to the state of the art (TCP or UDP).

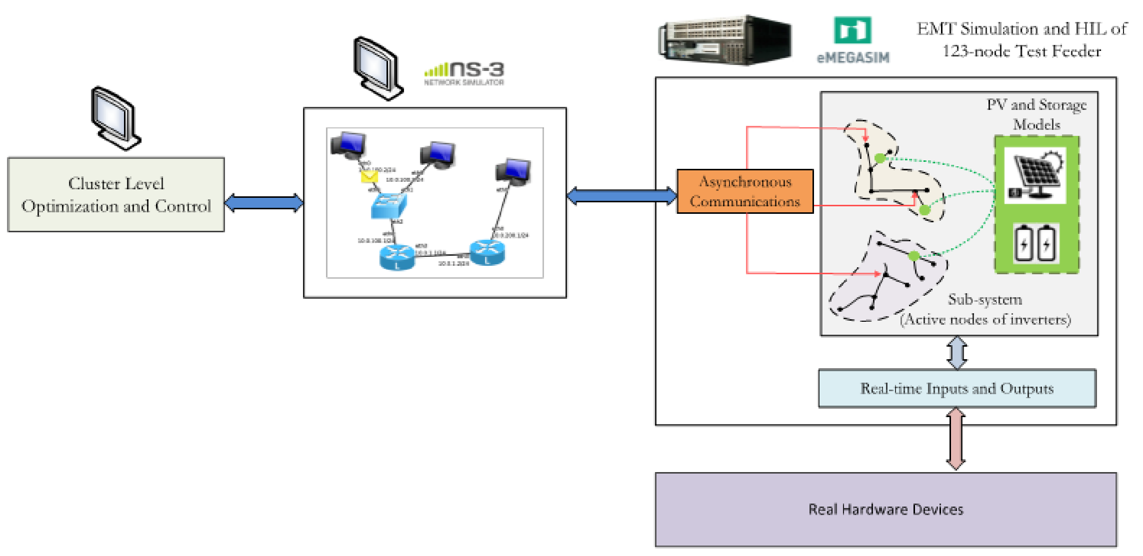
Technical Details of each Module

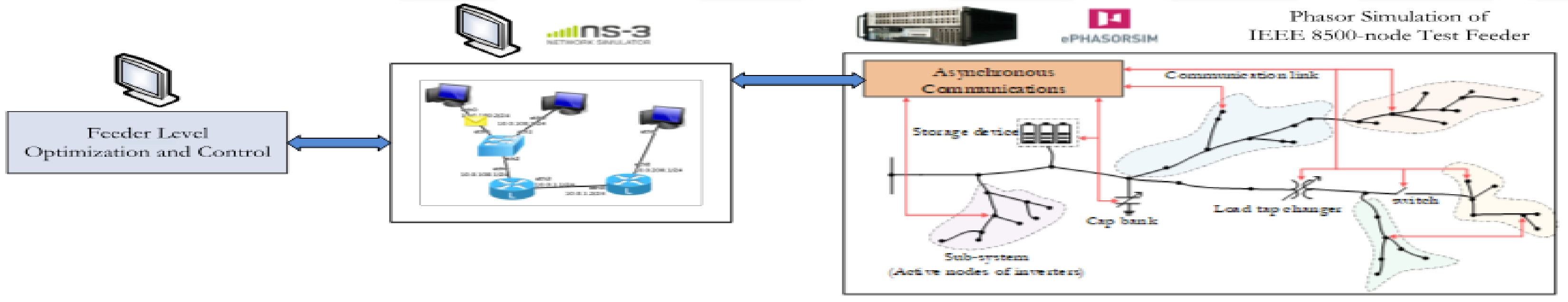
Module 7: Overall Implementation

<u>Objectives</u>: Develop a phasor and EMT domain model sof the large-scale grid and evaluate the tool using real-time simulation.

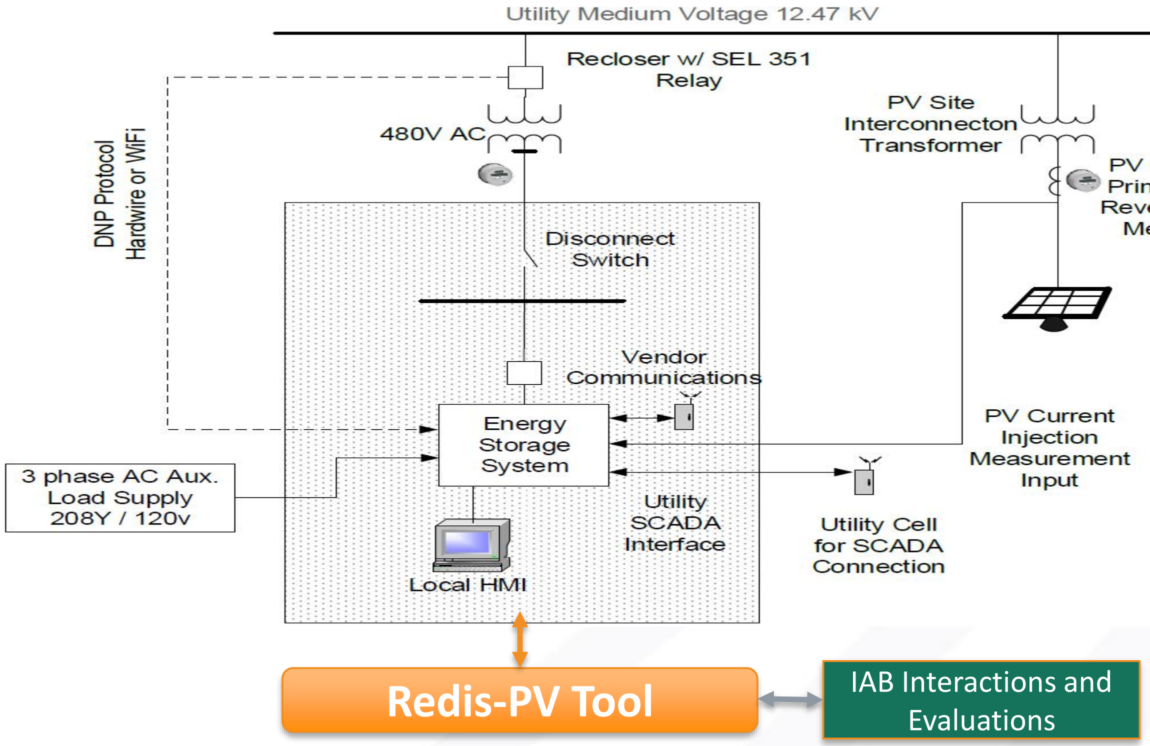
<u>Key Innovative Aspects</u>:

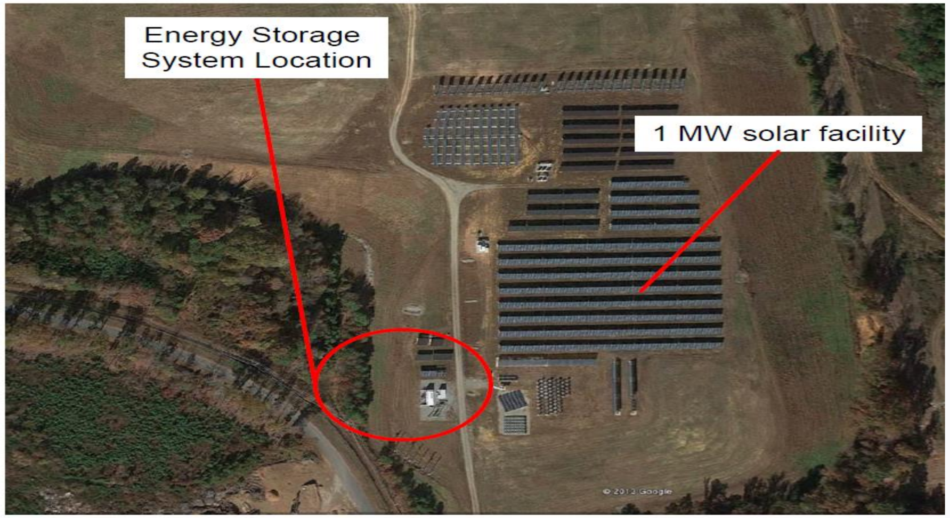
- Fully Integrated real-time model
- Integrated communication layer
- Hardware-in-the-loop testing





Proposed Demonstration Site





- **Duke Support and Involvement**
  - Sub transmission network one-line diagram and transformation information for modeling.
  - Two distribution feeder models and potential DER information and sizes based on future plans.
  - Substation transformer and feeder OLTC information including voltage, power archived data set.
  - Relay settings and coordination curves between relays, reclosures, switches.
  - Communication infrastructure information including delays and network security protocols.
  - Utility SCADA connection points and DMS output information as obtained from SCADA and archival.

- **Duke Support and Involvement**
  - Help to deploy the tool in the field and demonstrate the controller on one implementation system as indicated in the potential site shown above.
  - Help supporting the industrial advisory board and member selection for fleet wide deployment.
  - Help decide the deployment process and selecting third party vendor for developing professional grade framework.

- **Other Advisors**
  - IAB Interactions and Evaluations

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